OPEN EUROPEAN JOURNAL ON VARIABLE STARS
Januray 2024 http://oejv.physics.muni.cz ISSN 1801-5964
DOI: 10.5817/OEJV2024-0244

STUDY OF THE VARIABLE STARS V10 AND C6 IN MESSIER 13

VIOLAT-BORDONAU, FRANCISCO

Observatorio Astronómico *Norba Caesarina*, 10195, Cáceres, Spain, fviolat@gmail.com

Abstract: We have studied the variable star V10 and the new variable candidate C6 (announced in 2019), located in Messier 13, using the filtered CCD images -in the *V* band- obtained in the campaigns of 2019, 2020 and 2021. We have previously determined their precise α and δ coordinates (J2000) to identify them in a crowded field. We find the V10 constant in light in the three campaigns: the star is listed in the Catalogue of Variable Stars in Globular Clusters as non-variable. C6 has presented low-level variations from 0.102 to 0.138 mag without regularity; these values are lower than 0.44 mag in the *V* band detected by its discoverers. Although we find different periods, none draw a coherent light curve. We have also analysed the photometric measurements obtained by ASAS-SN between 2019 and 2023 in the SLOAN-g band, identifying oscillations with a maximum amplitude equal to 0.188 mag;. However, we find two possible periods, none producing a quality light curve. All data suggest that C6 is a new variable star of type L, irregular because no single period fits all of the data: we propose the name V65 for it.

1 Introduction

This paper aims to investigate one (C6) of the 15 candidate variable stars in Messier 13, presented in 2019, to confirm their variable status using our more extensive photometric data. We also take this opportunity to publish some corrections of mistakes in the literature regarding variable star identification and astrometric coordinates of V10 and C6.

Recently, Deras *et al*. (2019, hereafter DER19) presented fifteen candidates for variables in Messier 13, nominating them C1 to C15, with amplitudes ranging from 0.04 (C1 and C13) to 0.44 mag (C6) in the *V*-band. They provided α and δ coordinates (J2000) for these candidates, along with a precise chart of the cluster's variables and candidates (Figure 2 in their work). After verifying the position of C6, we were noted to coincide with the variable star V10 (Sawyer, 1940), also known as L487 (Ludendorff, 1905), with a slight difference. The electronic version of the Catalogue of Variable Stars in Globular Clusters (Clement et al., 2022) indicates that its position is very close to that provided by Sawyer; both stars could be the same misidentified star.

V10 is located not far from the core (Figure 1), in its southern part, between the variable stars V24 (to the east) and V11 (to the west). In this position, a chain of three stars appears, named, in order of right ascension, L470 = BARN 103 (Barnard, 1931), BARN 105, and L487 (V10). Taking BARN 105 as a reference, both stars are at distances of 2.80” (V10) and 2.33” (L470) according to SIMBAD; however, if we use V10 as a reference, the distance to L470 is 4.55”, and to C6 is 5.02”. A careful examination of our best images (Figure 2) shows only one star in the position of L470, so both stars (L470 and C6) are the same, with a small

DOI: 10.5817/OEJV2024-0244

error explained by their proximity. It is easy to confuse them when working with short focal length telescopes (F < 4000 mm) and images of medium or low resolution.

L487, BARN 105 and L470 are red giant stars belonging to Messier 13 from Gaia's parallax (Bailer-Jones *et al*., 2021), one of the brightest (*V*~ 5.8 mag.) and best known of the globular clusters in the constellation of Hercules (α = 16h 41' 41.24", δ = +36º 27' 35.5", J2000); the distance to the cluster was estimated as 7.1 ± 0.1 kpc, with an average metallicity of [Fe/H] = -1.58 ± 0.09 and an age of 12.6 Gyrs (DER19).

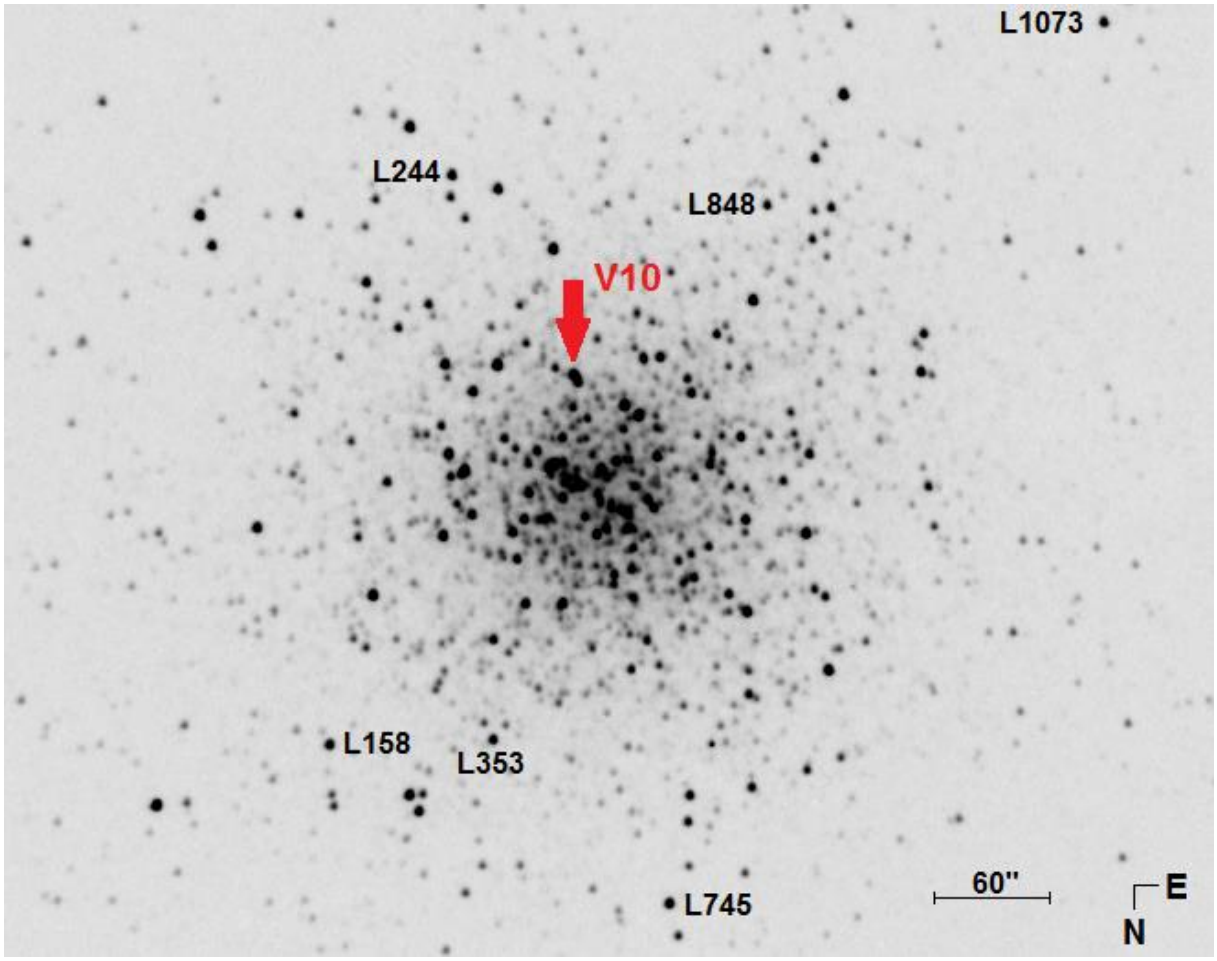

Figure 1: The CCD observed field of Messier 13 with labeled stars: V10, L158, L244, L353, L745, L848 and L1073. North is down, East to the right.

2 Accurate Astrometry: V10 and C6

We have observed the area very carefully in CCD images obtained by us between 2009 April and September at the "Observatorio Astronómico de Forcarei", located in Forcarei (Pontevedra, Spain), belonging to the Departamento de Astrofísica de la Universidad de Vigo and the *Fundación FC*[3]. These images were captured using a 0.5-m telescope with a focal

DOI: 10.5817/OEJV2024-0244

length of 4,075 mm, equipped with a SBIG ST-L camera (with 9-micron pixels) and RGB colour model filters, close to the *BVR* system but not identical. Figure 2 (taken with photographic filter B) presents an enlargement of the area where V10 and C6 are located; in the upper right corner of this figure, there appears to be an enlargement of the mentioned star chain: V10 and C6 are very close, but resolvable, separated by the star BARN 105.

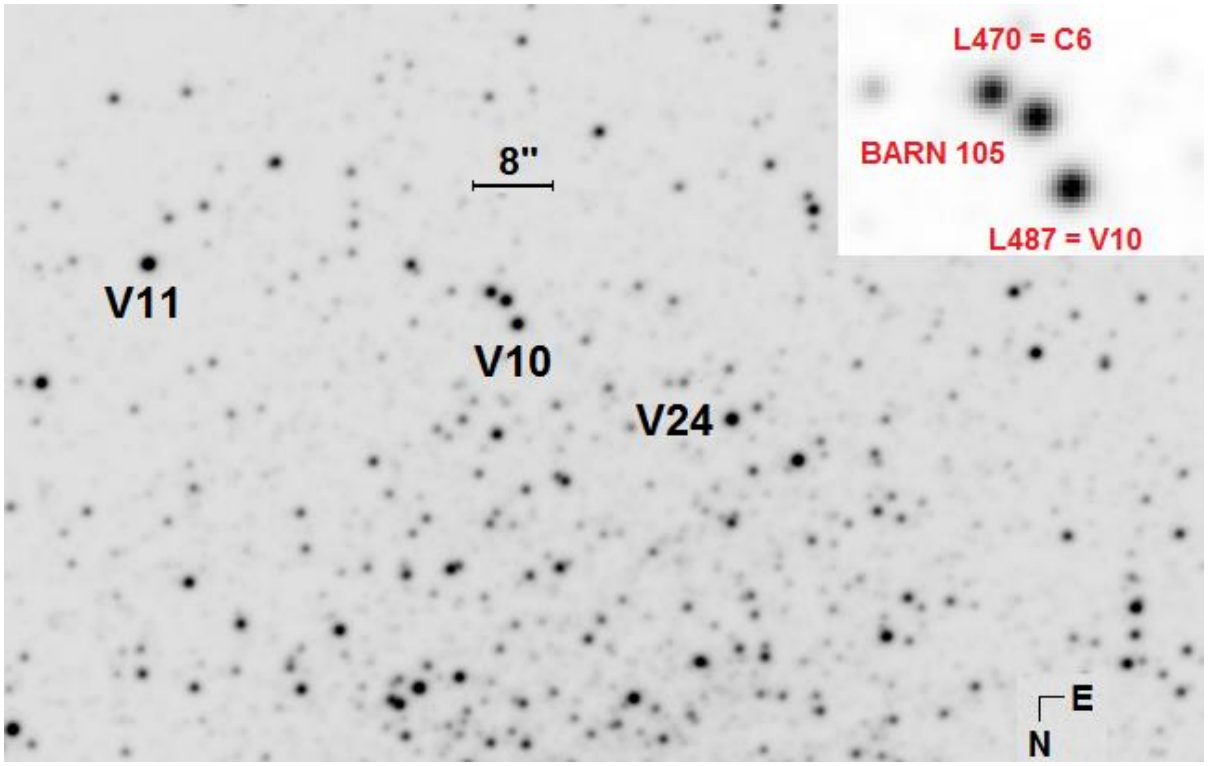

Figure 2: Central region of Messier 13, taken with photographic filter B, with the variable stars V10, V11 and V24. The panel on the right contains the stars L470 (C6), BARN 105 and V10 (L487).

We have determined α and δ coordinates (J2000) of the three stars using several very high-resolution CCD frames, obtained with a B photographic filter (similar to the *B* Johnson), and short exposures (20 to 30 seconds) to reduce the size of the stars on the chip: from one of these frames we have prepared Figure 2 and its enlargement. To obtain these coordinates, we have used the commercial program *Astroart* (from MSB Software): the frames have been opened and calibrated using the coordinates published in SIMBAD of the six stars listed in Table 1 (Figure 1)**:** which presents the coordinates (J2000) of comparison and check stars taken from SIMBAD and their *V* magnitudes and *B* – *V* colour index from Stetson *et al.* (2019, hereafter STE19).

DOI: 10.5817/OEJV2024-0244

Table 1: Comparison and check stars

Star	ID	RA (J2000) [h:m:s]	DEC (J2000) [° ' "]	*V* [mag]	*B* – *V* [mag]
L745	2MASS J16414486+3630514	16:41:44.85	+36:30:51.37	12.490	1.293
L244	2MASS J16413437+3625048	16:41:34.36	+36:25:04.76	12.602	1.225
L158	2MASS J16413053+3629434	16:41:30.52	+36:29:43.44	12.675	1.144
L353	2MASS J16413725+3629368	16:41:37.24	+36:29:36.77	12.809	1.138
L1073	2MASS J16420085+3623338	16:42:00.84	+36:23:33.67	12.859	1.087
L848	2MASS J16414739+3625111	16:41:47.40	+36:25:11.13	13.110	1.071

Astroart identifies between 2,200 and 2,500 stars in each frame (Figure 3), depending on the quality of the plate, providing their coordinates with high precision. In Table 2 we show the values obtained by us for the three stars that we analyse in this work:

Table 2: Astrometry

Star	RA (J2000) [h:m:s]	DEC (J2000) [° ' "]
L470 (C6)	16:41:39.720	+36:26:37.62
BARN 105	16:41:39.852	+36:26:38.43
L487 (V10)	16:41:39.958	+36:26:41.24

Figure 3, made with *Astroart*, shows the area around V10 and C6: variable stars V11, V7, V24, and V39 have also been labelled. The α and δ (J2000) positions of 2,321 stars have been identified in the frame; the upper panel shows the coordinates of the stars identified: the first three stars are L470 (C6), BARN 105 and L487 (V10). All the stars that appear in the frame, until magnitude 19 *B*, are identified by the software inside a small green square centred on its photocenter. We can verify that the software perfectly solves the stars chain, including C6, BARN 105 and V10. The position of V10 is not easy to measure. Each observer obtains a different value, as we will see in Table 3: we compare them with those provided by Osborn (2000, hereafter OSB00), Kopacki *et al.* (2003, hereafter KOP03), this paper and SIMBAD; the differences between them, very small and less than 0.3", are due to stellar crowding and the difficulty in separating them if the seeing is not reduced.

DOI: 10.5817/OEJV2024-0244

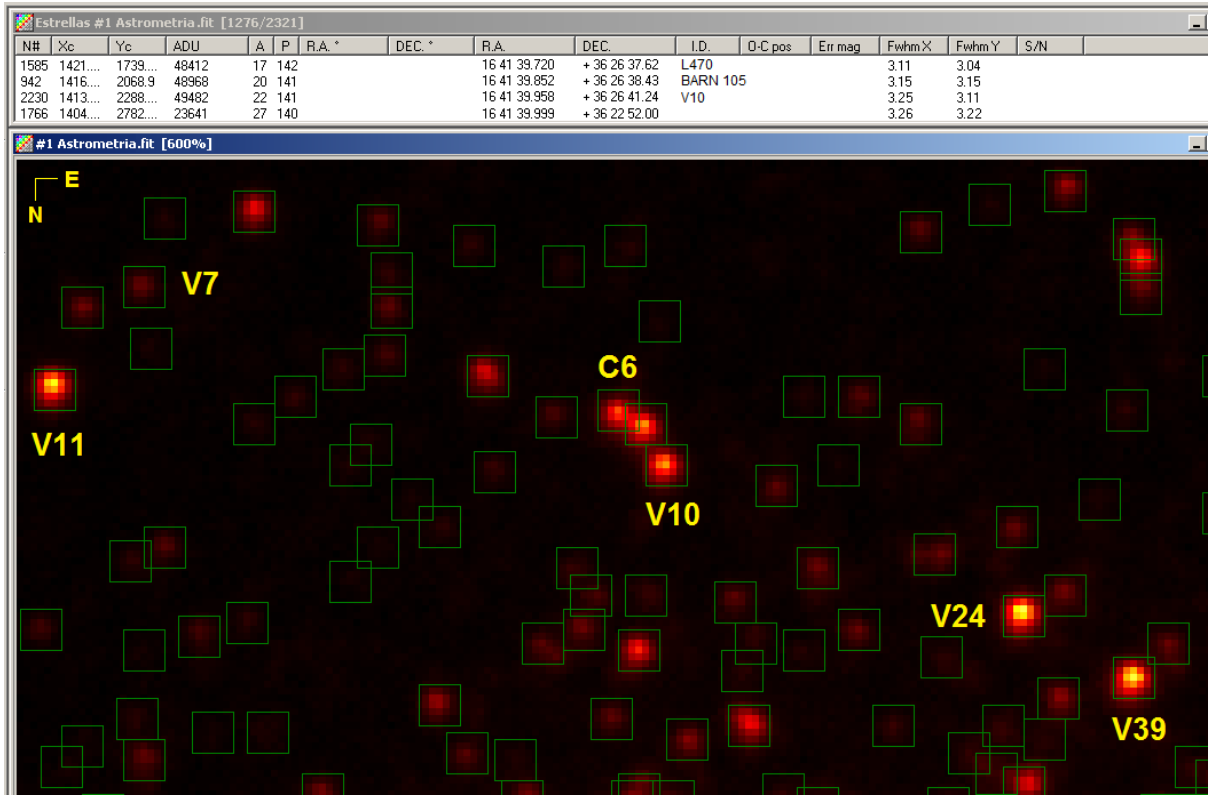

Figure 3: South region of the cluster centered on V10 and C6. Coordinates of four of the 2,321 stars identified in the frame appear at the top of the figure. North is down, East to the right.

Table 3: V10 coordinates

Author	RA (J2000) [h:m:s]	DEC (J2000) [º ' "]
Osborn (2000):	16:41:40.01	+36:26:41.5
Kopacki *et al.* (2003):	16:41:39.96	+36:26:41.3
Violat (2023):	16:41:39.96	+36:26:41.2
SIMBAD:	16:41:40.01	+36:26:41.5

SIMBAD values were taken from Osborn's paper; for that reason, the data are identical; note that the differences between them are small: 0.05s in α and 0.2” to 0.3” in δ (in our case, this value is close to the theoretical resolving power of the telescope used: 0.24”).

DOI: 10.5817/OEJV2024-0244

3 Photometry

3.1 Photometry of V10 and C6 (2009)

To obtain colour images of Messier 13, and other clusters, we capture images at the "Observatorio Astronómico de Forcarei" with R, G and B photographic filters between 2009 April and September. We have recovered and analysed for this paper these CCD frames obtained with the G filter (green, similar to the *V* Johnson): after calibrating them with the stars listed in Table 1, we verified that the data obtained are not sufficient to obtain light curves of V10 and C6, since they are not well distributed nor are they photometrically accurate, as the filters are not identical, but they do allow us to obtain two important conclusions:

1) V10 is not variable: it appears at a constant magnitude throughout the entire campaign.

2) C6 presents slight oscillations with a maximum amplitude $\Delta G < 0.20$ mag.

Kadla *et al.* (1976) found V10 of magnitude 12.53 *V* and colour index *B* – *V* equal to 1.17. Pike & Meston (1977) classified it as a semiregular variable with a maximum amplitude $\Delta V = 0.07$ mag in the range 12.47-12.54 *V*, and a colour index *B* – *V* variable in the range 1.23-1.33. Shortly after that, Russeva and Russev (1980) presented a low-quality light curve of the star with a period equal to 35.62 days and an amplitude $\Delta B \sim 0.5$ mag: these researchers correctly attributed the scattering to the presence of a nearby optical companion and to the difficulty in measuring them. The non-variability of V10 has been confirmed by Osborn & Fuenmayor (1977), OSB00 and KOP03. STE19 include in their work these three stars and tabulates their magnitudes *B*, *V* and Variability Index V.I. (the probability of being variable) that we show in Table 4:

Table 4: Magnitudes *B*, *V* and Variability Index

Star	*B* [mag]	*V* [mag]	V.I.
L470	14.025	12.951	0.703
BARN 105	13.867	12.668	0.772
L487	13.800	12.569	0.650

With these low Variability Index none of the stars seems to be variable, or their amplitudes are very small.

3.2 New Photometry (2019-2021). Observations and data reductions

With these two conclusions in view, we have obtained *V* photometry of the CCD frames obtained in the 2019, 2020 and 2021 campaigns from Cáceres (Spain), all extending between June and October of each year. Since the spring of 2019 we have studied the variable very carefully and suspected variable stars of Messier 13: we employed the 0.2-m telescope f/10 of the "Observatorio Astronómico *Norba Caesarina*", at Cáceres, Spain, located at 455 m above sea level, to obtain time-series imaging of the globular cluster: all cluster frames were corrected via numerous bias and sky flat field images through standard procedures, and bias and twilight flats were taken every observing night.. The image data were obtained during several runs between 2019 June and 2021 October, where we collected a total of 482 (2019), 708 (2020) and 1,163 images (2021) through Johnson *V* filter, respectively (see Table 5 for a detailed log of the observations): the exposure times were always 120 s; on most nights the weather was very good and he seeing varied over a rather wide range, between 1.5 and 3.5 arcsec, with a typical value of 2.5-3.0 arcsec. The CCD camera is a Starlight Xpress MXV-7, of 752 × 580 pixels, with a scale of 0.90"/pixel and a field of view of 11.4 × 8.5 arcmin^2 (Figure 1): the resolution obtained has prevented us from reaching to solve V10 of C6 and BARN 105, except in some frames obtained on nights with very good seeing (from 1.5" to 2.5"). We have also observed other variable stars in the cluster, obtaining light curves and determining periods and amplitudes: Figure 4 is an example.

Table 5: Observational log

Year	H.J.D. Start	H.J.D. End	Nights	Images
2019	2458672.576	2458770.339	99	482
2020	2459005.665	2459136.337	132	708
2021	2459369.667	2459507.306	139	1,163

The photometric data were reduced using the software *FOTODIF* [1] (FOTOmetría DIFerencial, differential photometry) and calibrated using three stars of very well-determined *B* and *V* magnitudes, published in the photometric study by STE19, using an internal photometric ring with a diameter of 6 pixels, which is equivalent to a field equal to 5.4": the three stars appeared simultaneously in its interior, always measuring the combined brightness. Since neither V10 nor BARN 105 are variables, we record and measure the oscillations produced only by the variable star C6. The CCD finder chart (with labelled stars) is shown in Figure 1: the magnitudes were determined relative to L745, L158 and L848, whose constancy during the run was confirmed using L244, L353 and L1073. Table 1 presents the coordinates (J2000) of the comparison and check stars taken from SIMBAD and their *V* magnitudes and *B* – *V* colour index from STE19. This calibration procedure with three stars works perfectly: in

[1] Written by Julio Castellano, http://www.astrosurf.com/orodeno/fotodif/index.htm

DOI: 10.5817/OEJV2024-0244

Figure 4 we present the light curves of the variable stars V33 (upper panel) and V38 (lower panel) throughout the 2021 campaign; in both, we can see the behaviour of both stars over the weeks, and both are coherent without showing any strange or unexpected effect on them. Our photometry is accurate and allows us to detect oscillations of a few hundredths of a magnitude in these light curves. This data set, 2,353 points, covers from HJD 2458672.576 to HJD 2459507.306: 836 nights (Figure 5); the frames have been captured night by night starting at the same zenith height, which has minimised errors due to the atmosphere. The measured amplitudes (Table 6) are, in all cases, less than 0.139 mag in *V* band and have ranged between 0.102 (2020) and 0.138 mag (2019). The average (combined) brightness of the three stars has oscillated between magnitudes 11.636 ± 0.025 *V* (2019) and 11.650 ± 0.026 *V* (2021), being coherent between them despite the difficulty in obtaining photometry in an area of stellar crowding so close to the core.

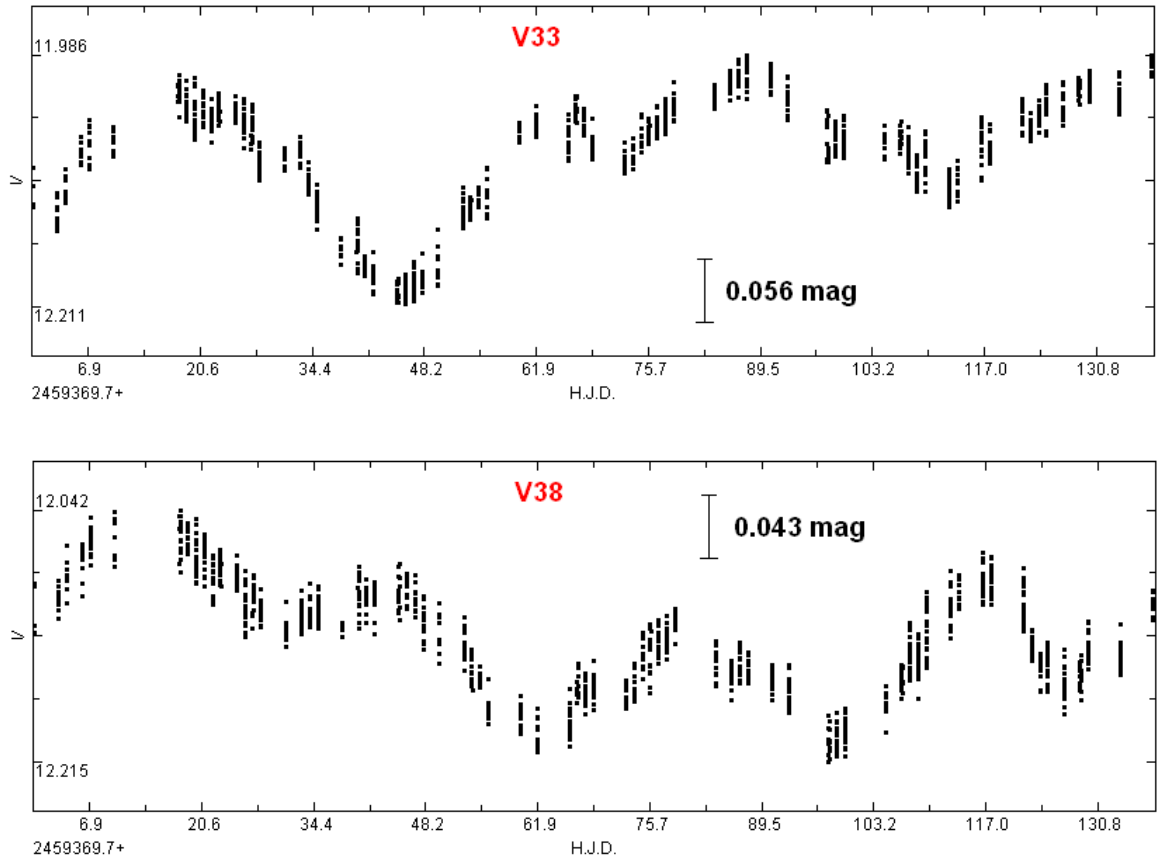

Figure 4: Light curves of the variable stars V33 (upper panel) and V38 (lower panel) obtained throughout the 2021 photometric campaign: both are semiregular red giants. Our equipment has allowed us to capture very small oscillations represented by the bars in each panel.

DOI: 10.5817/OEJV2024-0244

Table 6: Average *V* magnitudes, amplitudes and ranges of variability (ΔV)

Year	*V* [mag]	Amplitude [mag]	ΔV [mag]
2019	11.636 ± 0.025	0.138	11.582-11.720
2020	11.643 ± 0.023	0.102	11.596-11.698
2021	11.650 ± 0.026	0.127	11.593-11.720

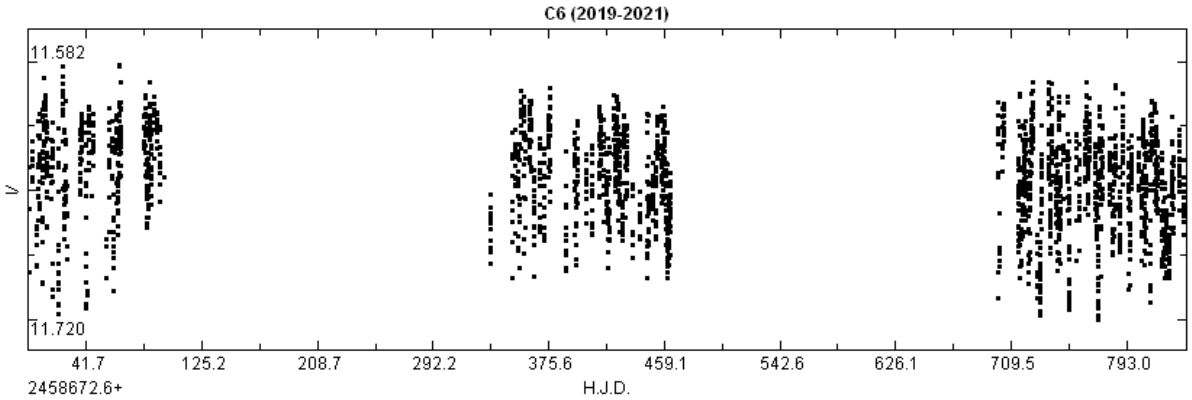

Figure 5: Light curves of C6 of the years 2019 (left), 2020 (center) and 2021 (right) in *V* band.

4 Data analysis

The analysis of the 2,353 points has been carried out with *A.V.E.* (*Análisis de Variabilidad Estelar*), from the "Grupo de Estudios Astronómicos GEA", using the Scargle Algorithm (Scargle, 1982). In Figure 6 we show the periodograms obtained: in the upper panel in the interval 1-145 days and the lower panel in the interval 1-30 days. Two unremarkable long periods (69.4 and 86.4 days) and a group of four to six short periods of 12.9 to 24.1 days appear: none of them produce a good quality coherent light curve. Table 7 shows the periods obtained from the measurements of each campaign. The data suggest that C6 is an irregular variable of reduced amplitude: $\Delta V < 0.139$ mag in *V* band.

Table 7: Periods of the variable C6 (days)

Year	Points	P1	P2	P3	P4
2019	482	6.66	1.17	4.23	19.17
2020	708	6.82	1.16	0.87	16.05
2021	1,163	13.11	1.04	22.53	18.09
All	2,353	13.40	12.94	18.20	24.11

DOI: 10.5817/OEJV2024-0244

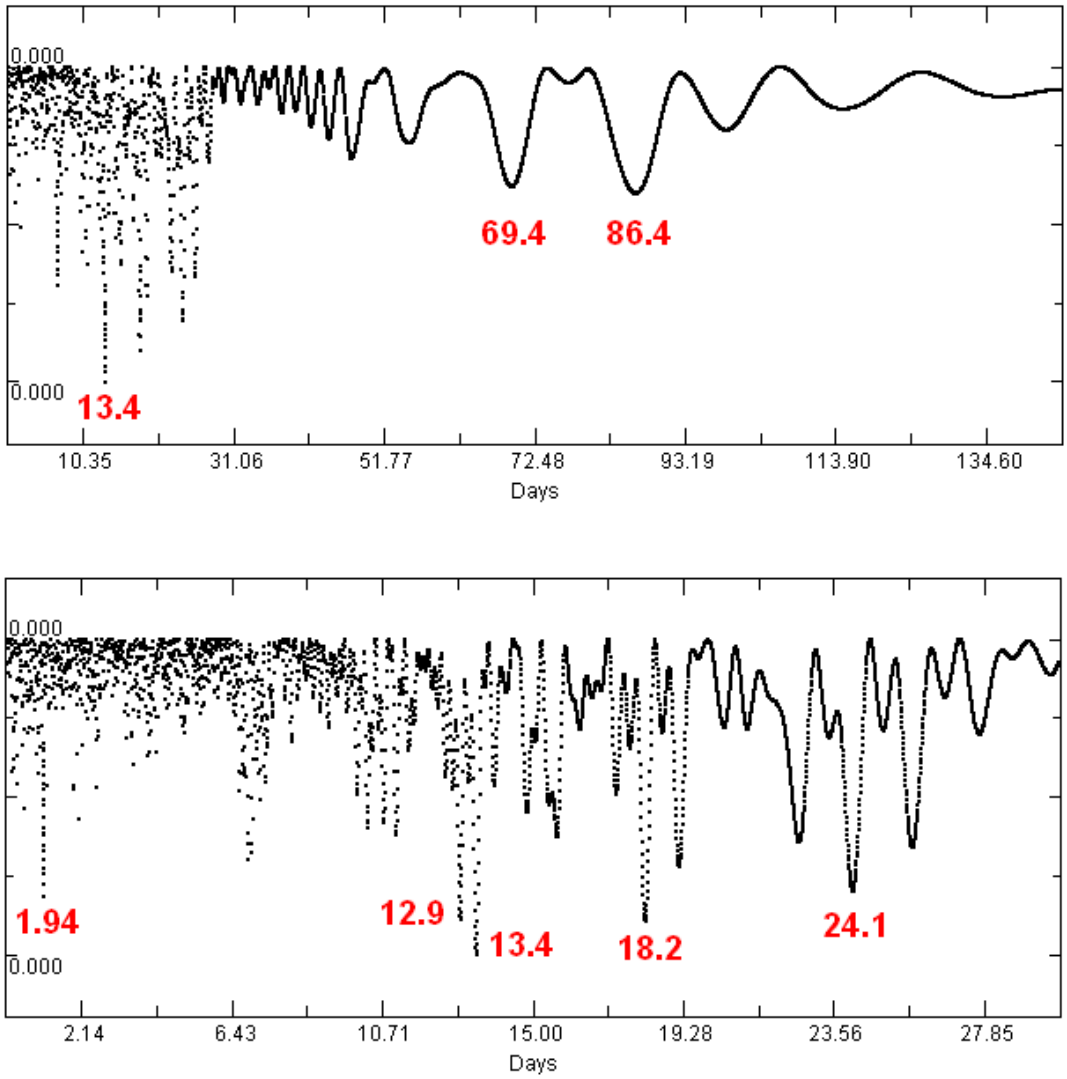

Figure 6: Periodograms obtained from our 2,353 photometric measurements in the interval 1-145 day (upper panel) and 1-30 days (lower panel).

5 ASAS-SN photometry (2019-2023)

To confirm these results, we have downloaded the measurements obtained by the ASAS-SN automatic system (Jayasinghe, T. et al., 2018; Shappee, B. J. et al., 2014; Kochanek et al., 2017) in the SLOAN-g band. We have analysed a total of 3,495 points obtained between 2019 January and 2023 November (Figure 7): after eliminating some anomalous measurements that differed from the others in several tenths of a magnitude, we verified that the amplitude Δg = 0.188 mag, similar to that recorded by from our measurements in part of the same time period studied (2019-2021).

DOI: 10.5817/OEJV2024-0244

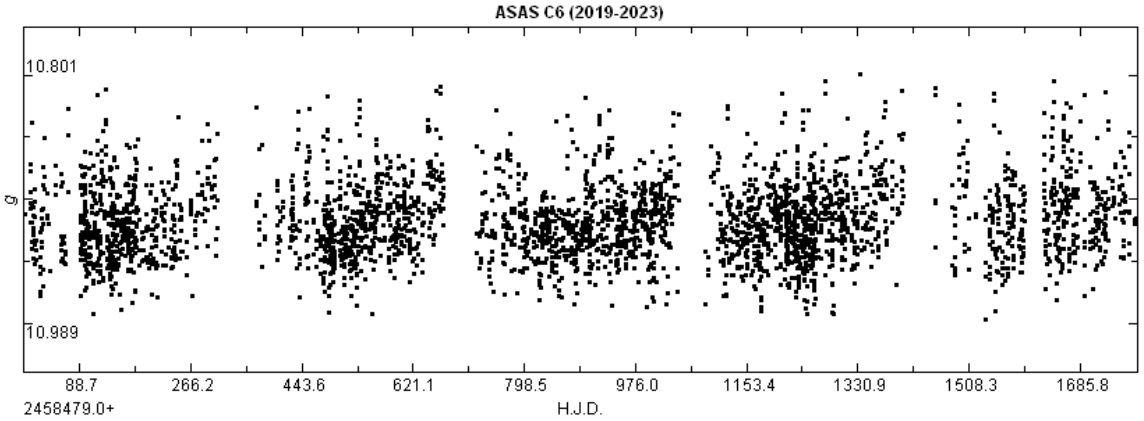

Figure 7: Light curves of C6 of the years 2019 (left) to 2023 (right) in SLOAN-g band.

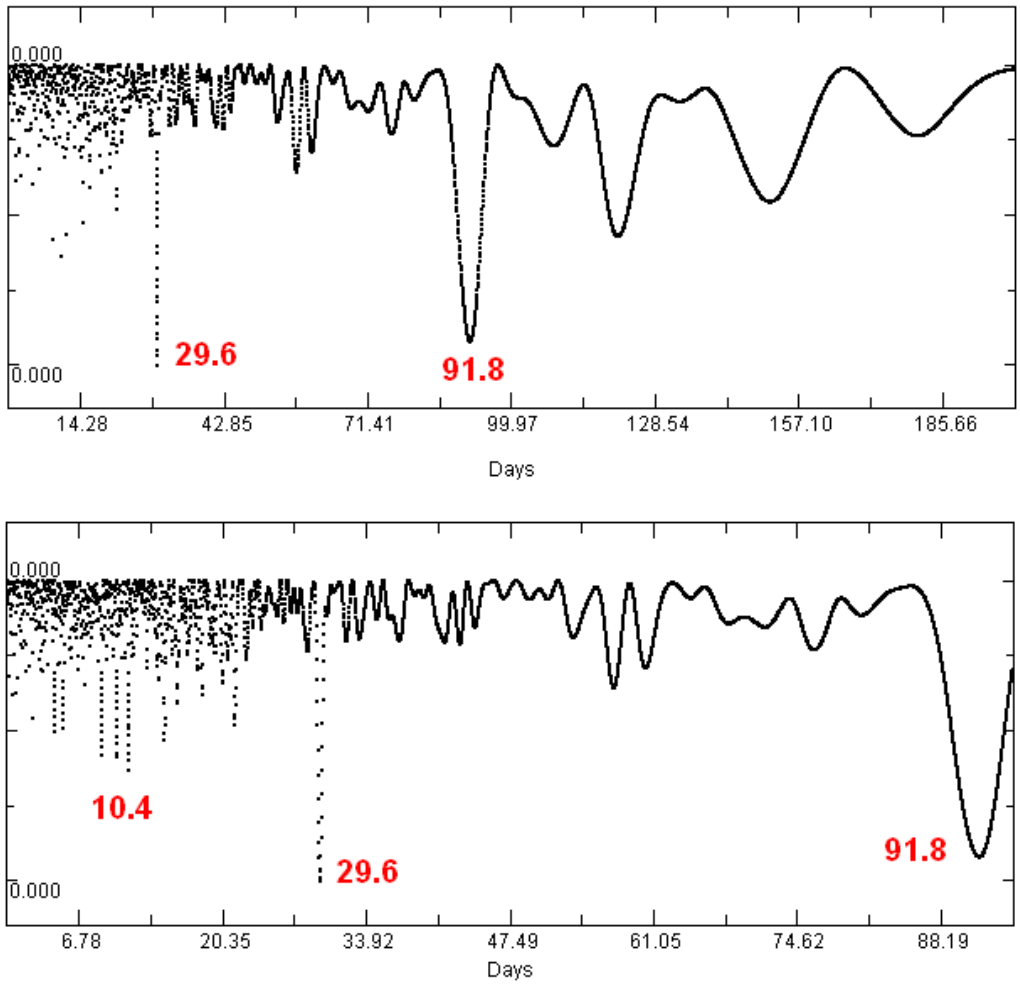

Figure 8: Periodograms obtained from ASAS-SN photometric measurements in the interval 1-200 day (upper panel) and 1-95 days (lower panel).

DOI: 10.5817/OEJV2024-0244

The search for the period has been carried out in the same way as that used with our measurements in the interval 1-200 days (Figure 8, upper panel) and 1-95 days (lower panel): we found a short, very prominent period, equal to 29.60 days (very close to a synodic month, 29.53 days, the period of the lunar phases and the annoying presence of the full Moon) and another length equal to 91.8 days; a group of shorter periods also appear, as in the previous case, the most notable being equal to 10.4 days: none of them produces a quality light curve, which confirms our results. Recently L470 (C6) has been listed in the work *15 000 ellipsoidal binary candidates in TESS* (Green *et al.*, 2023) as a variable star, of reduced amplitude, with a period equal to 4.589263 days.

6 Discussion

As the C6 star is a candidate for short-period ellipsoidal binary (P < 5 days) we have analysed the periodogram of the data of each campaign, in the interval 0.1-5.0 days. We observe with surprise (Figure 9), that in all three cases a very marked, almost identical value appears: Table 8 shows these results. When drawing the light curves with these values (Figure 10), surprisingly, it is of moderate quality and shows the maximum and minimum, which did not happen with any other period. The analysis of the ASAS-SN data (Figure 9, lower panel) offers a very marked value (0.919775 days) and two other some somewhat shorter (0.865389 and 0.868064 days) similar to those obtained from our measurements: it is evident that these values are real and occur by some physics mechanism of the binary system, however when using the period obtained by Green *et al.* no results are obtained on these data.

Table 8. Periods

Year	Value (days)
2019	0.867398
2020	0.870026
2021	0.926705
ASAS-SN	0.919775
	0.865389
	0.868064

DOI: 10.5817/OEJV2024-0244

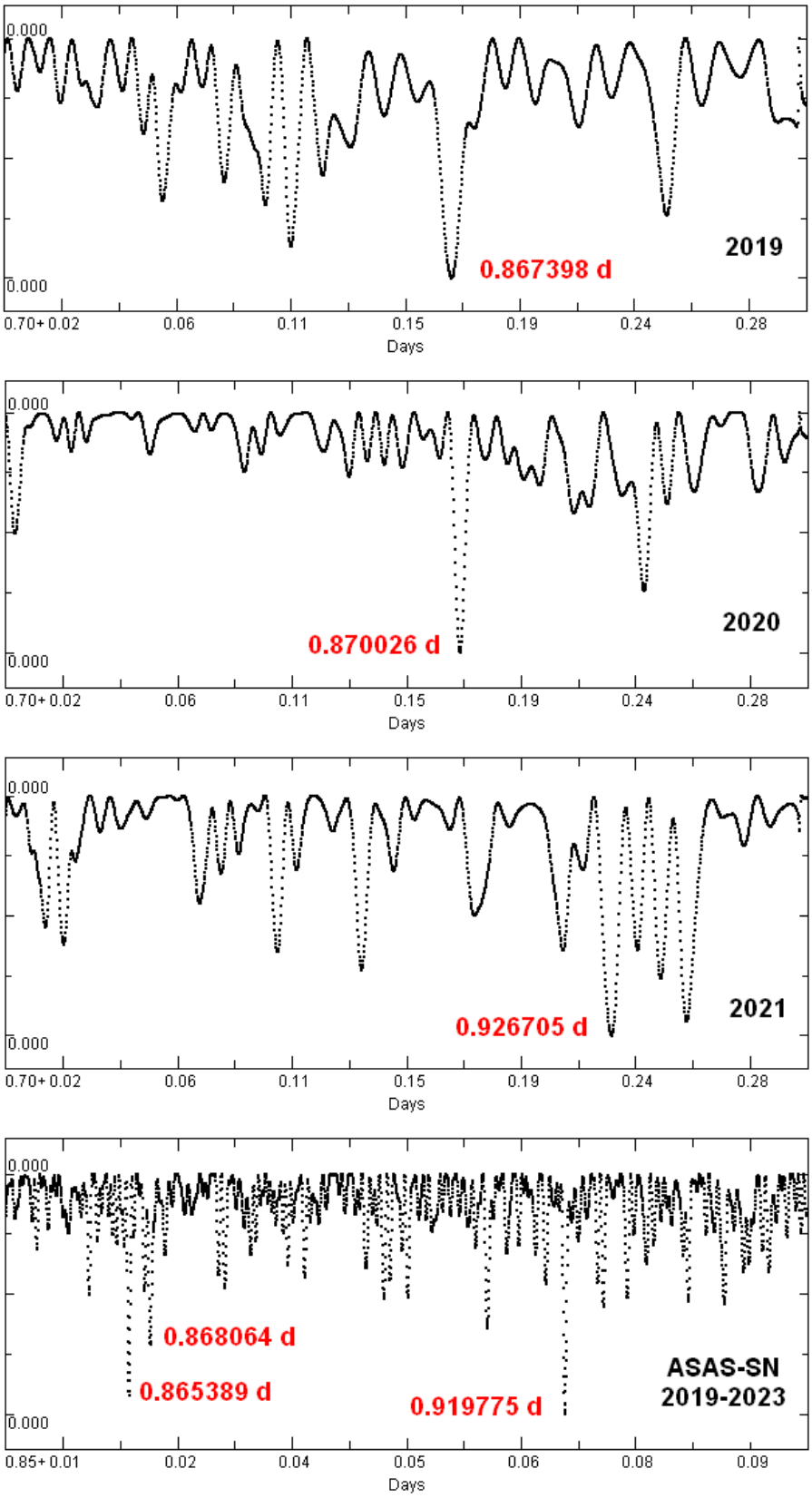

Figure 9: Periodograms obtained from our data (2019, 2020 and 2021) in the interval 0.70-1.00 days, and ASAS-SN photometric measurements (2019-2023) in the interval 0.85-1.00 days.

DOI: 10.5817/OEJV2024-0244

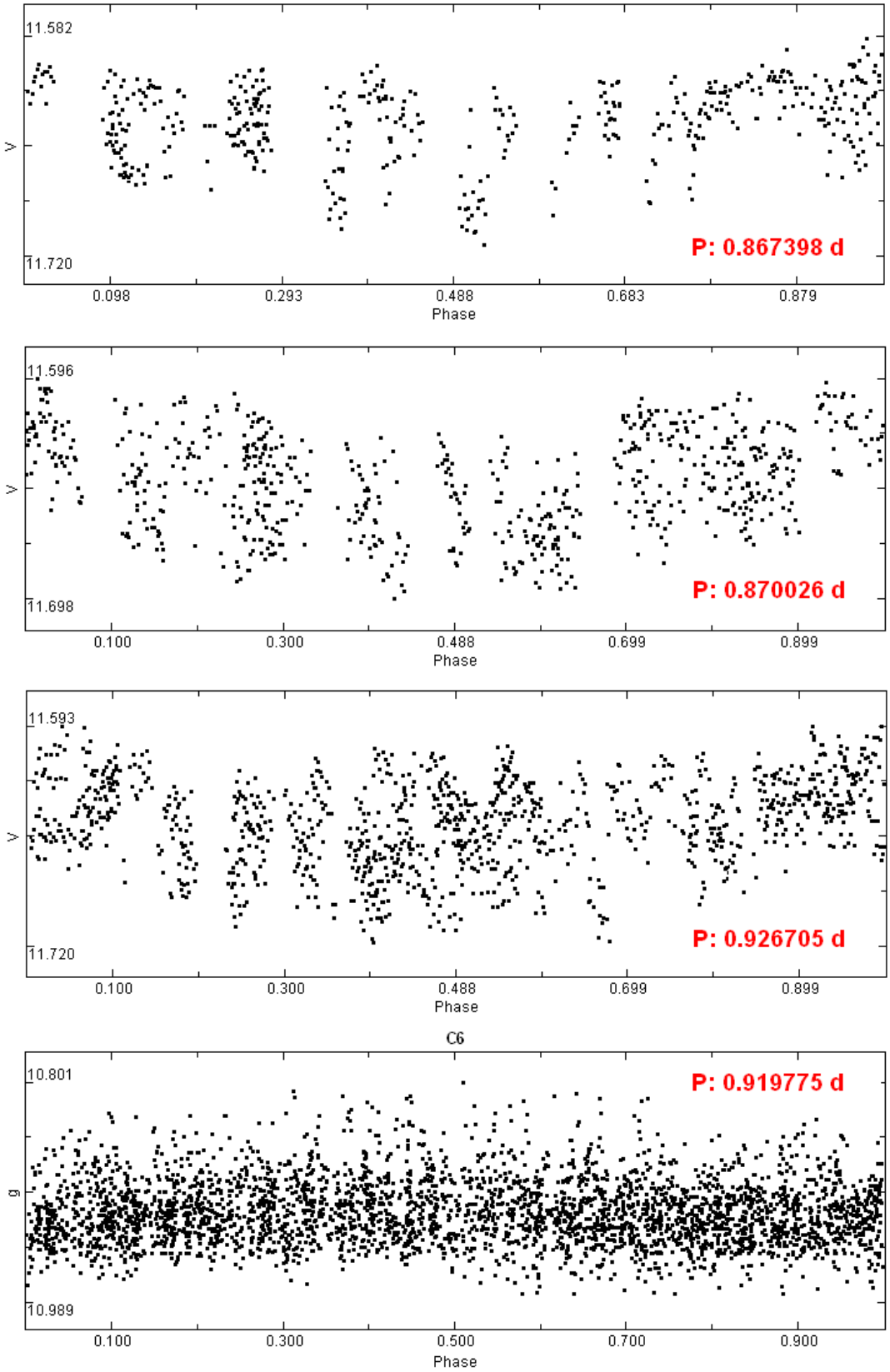

Figure 10: Light curves of C6 of the years 2019 (upper panel), 2020 (central panel) and 2021 (lower panel) drawn with the periods obtained. The last curve of light (above these lines), a sinusoidal wave, is from ASAS-SN data with the most prominent period (P: 0.919775 days).

DOI: 10.5817/OEJV2024-0244

7 Conclusions

Using filtered CCD images obtained in four different campaigns (2009 and 2019-2021), we verified that the variable star V10 (L487) is constant in light, confirming the results obtained in the past by different researchers. After carefully examining its coordinates, we verify that the star L470 is undoubtedly the candidate for variable C6, announced by DER19 in 2019. We measure oscillations from 0.102 to 0.138 mag in the *V* band, according to the campaign, without regularity: surprisingly, these values are below 0.44 magnitudes in the *V* band detected by its discoverers, probably because we have measured, at the same time, the combined magnitude of three stars as they cannot solve them individually in our frames. Although we find different periods, none draw a coherent light curve. We have analysed the photometric measurements obtained by ASAS-SN between 2019 and 2023 in the SLOAN-g band, identifying oscillations with a maximum amplitude equal to 0.188 mag; we find two possible periods, but none of them produces a quality light curve.

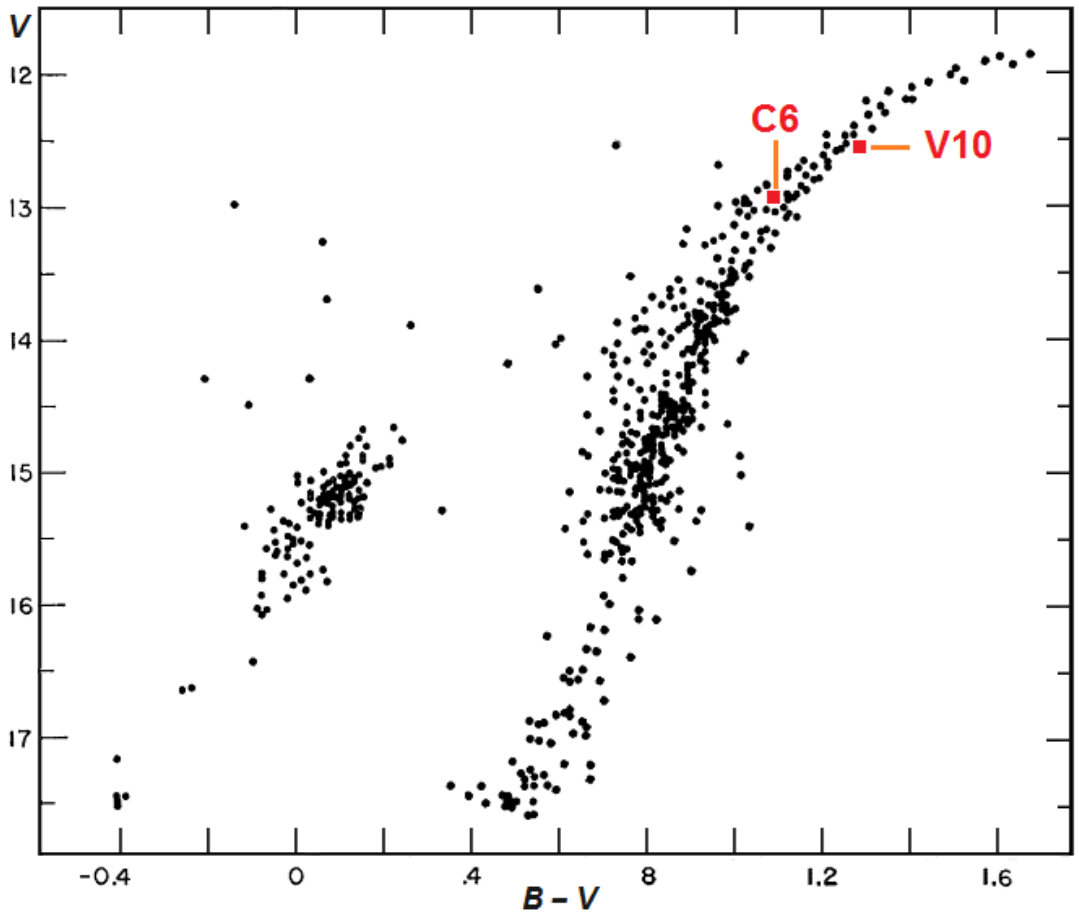

Figure 11: Color-Magnitude diagram obtained by Arp and Johnson (1955): in it we have marked the position of C6 and V10 in the Red Giants Branch.

DOI: 10.5817/OEJV2024-0244

Very recently, Green et al. (2023) list in their work L470 as a binary ellipsoidal variable with a period equal to 4.589263 days. We find a very short period in all the data analysed, between 0.87 and 0.93 days according to the campaign, which also appears in the ASAS-SN data (~ 0.92 days), that they draw coherent light curves of medium quality. We include a Color-Magnitude diagram (Figure 11), taken from the work of Arp & Johnson (1955), on which we have marked the position of C6 and V10: both are bright stars located in the Red Giants Branch very close to the tip. All data suggest that C6 (L470) is a new irregular variable star of reduced amplitude. Since the last variable star recorded in the *CVSGC* is V64 (Violat-Bordonau, 2021) we propose for it the name of V65.

Acknowledgements

This paper is based on observations obtained at the "Observatorio Astronómico *Norba Caesarina*" (MPC Z71) at Cáceres (Spain), and the "Observatorio Astronómico de Forcarei" (Universidad de Vigo and *Fundación FC*^{3}). We are indebted and want to express here our gratitude to Juan-Luis González-Carballo (from the Grupo de Observadores de Supernovas) for his help in providing us with the ASAS-SN measurements and advising us with this type of data. We are also grateful to the referee for valuable comments. This research has also made use of the SIMBAD database, operated at CDS, Strasbourg, France, ASAS-SN data and NASA's Astrophysics Data System Abstract Service. The observational data used in this work are available upon request to Francisco Violat-Bordonau (fviolat@gmail.com).

References

Arp, H. C., Johnson, H. L, 1955, ApJ, 122, 171: 1955ApJ...122..171A
Astroart, MSB Software: *ASTROART*
AVE, Análisis de Variabilidad Estelar, G.E.A: *AVE Análisis de Variabilidad*
Bailer-Jones, C. A. L. *et al*., 2021, AJ, 161, 147: 2021AJ....161..147B
Barnard, E. E., 1931, Publ. Yerkes Obs., 6, 1-106: 1931PYerO...6....1B
Clement, C. M., 2017, VizieR On-line Data Catalog, V/150: *NGC 6205 (Messier 13)*
Deras, D., *et al*., 2019, MNRAS, 486, 2791: 2019MNRAS.486.2791D
FotoDif, Fotometría Diferencial, Julio Castellano: *FotoDif*
Green, M. J. *et al.*, 2023, MNRAS, 522, 29: 2023MNRAS.522...29G
Jayasinghe, T. *et al*., 2018, MNRAS, 486, 1907: 2019MNRAS.486.1907J
Kadla, Z. I. *et al.*, 1976, Soviet Astronomy, 20, 403: 1976SvA....20..403K
Kochaneck, C. S. *et al.* 2017, PASP, 129, 980, 104502: 2017PASP..129j4502K
Kopacki, G. *et al.*, 2003, A&A, 398, 541: 2003A&A...398..541K
Ludendorff, H., 1905, Publ. Astrophys. Obs. Potsdam, Vol. 15, Nº 50: 1905POPot..50....1L
Osborn, W., Fuenmayor, F., 1977, AJ, 82, 395: 1977AJ.....82..395O

DOI: 10.5817/OEJV2024-0244

Osborn, W., 2000, AJ, 119, 2902: 2000AJ....119.2902O
Pike, C.D., Meston, C.J., 1977, MNRAS, 180, 613: 1977MNRAS.180..613P
Russeva, T., Russev, R., 1980, IBVS, 1769: 1980IBVS.1769....1R
Sawyer, H. B., 1940. Public. David Dunlap Observatory, vol. 1, 179: 1940PDDO....1..179S
Scargle, J. D., 1982, ApJ, 263, 835: 1982ApJ...263..835S
Shappee, B. J. *et al*., 2014, ApJ, 788, 48: 2014ApJ...788...48S
Stetson, P. B. *et al*., 2019, MNRAS, 485, 3042: 2019MNRAS.485.3042S
Violat-Bordonau, F., 2022, OEJV, 222, 1: 2022OEJV..222....1V